# DYNAMICO
# Dynamical core on Icosahedral grid

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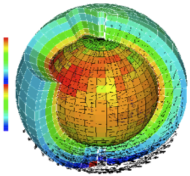
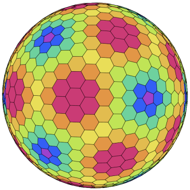




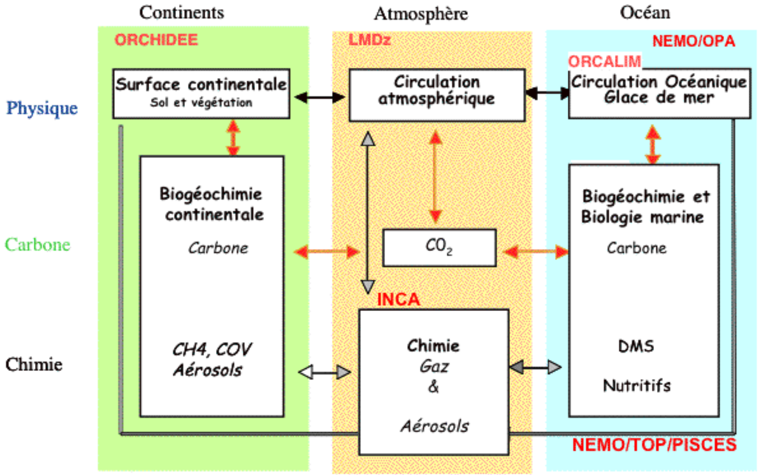
## DYNAMICO fact sheet

- hydrostatic, shallow-atmosphere
- icosahedral, hexagonal, C-grid, structured
- pressure-based hybrid terrain-following $\eta$ coordinate
- Lorentz vertical staggering
- mass- and enstrophy-conserving FD (Sadourny, 1975 ; Ringler et al., 2010)
- explicit 4-th order dissipation
- Eulerian positive definite, slope-limited transport (Dubey et al., submitted)

## Planned 2012-2013

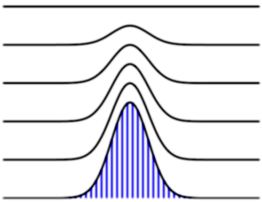
- quasi-hydrostatic, deep-atmosphere (M. Tort, PhD)
- energy conserving option
- coupling with LMD-Z physics package
- aquaplanet experiments

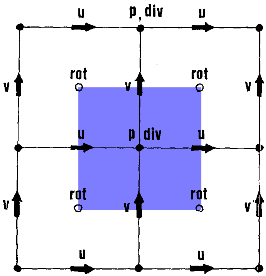
# Climate modelling at IPSL



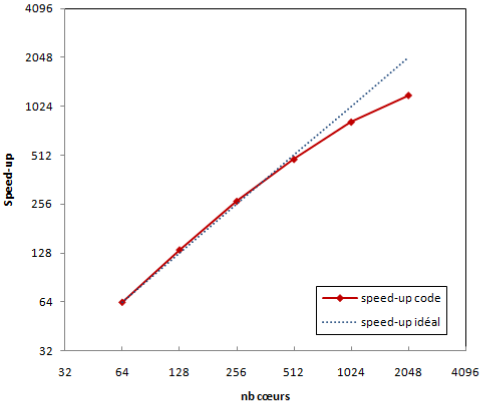
# The LMD-Z core

- hydrostatic, shallow-atmosphere
- lat-lon, C-grid + polar filters
- grid-stretching
- pressure-based hybrid terrain-following $\eta$ coordinate
- Lorentz vertical staggering
- mass- and enstrophy-conserving (Sadourny, 1975)
- explicit 4-th order dissipation
- Eulerian positive definite, slope-limited transport (Hourdin & Armengaud, 1999)
- used to model planetary atmospheres (Mars, Venus, Titan, ...)





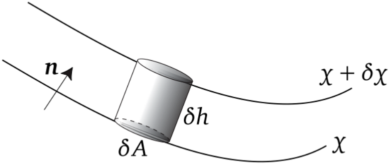
# Scalability




*Y. Meurdesoif (2010, 1/4 degree)*

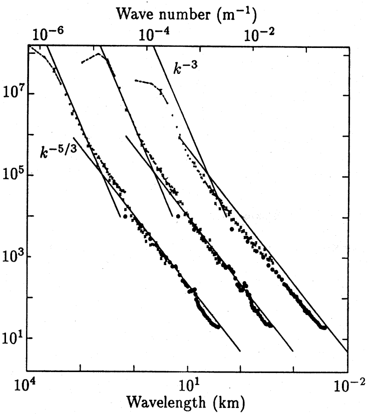
# Potential vorticity and (potential) enstrophy

- Conservation of potential vorticity implies limits on the generation of vorticity

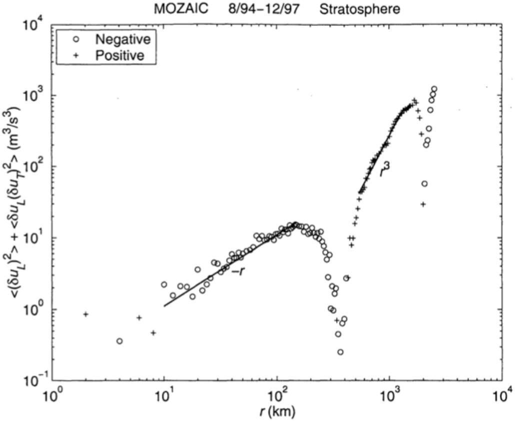



- At the discrete level, 3 levels of "vorticity conservation"
  1. Pressure gradient generates no vorticity
  2. Potential vorticity obeys an implied transport equation
  3. Potential enstrophy is conserved
- Conservation of energy and enstrophy tend to conflict with each other (Arakawa, 1966 ; Sadourny, 1975; Arakawa & Lamb, 1982 ; Ringler et al., 2010)

# Enstrophy vs energy




*Nastrom & Gage, 1985*




*Cho & Lindborg, 2001*

# The DYNAMICO project

## Goals & principles

- Revive an interest in numerical methods at LMD/IPSL
- Break the scalability bottleneck by moving LMD-Z to a quasi-uniform-grid
- Hydrostatic core an important milestone suitable for short-term application to climate modelling
- Provide at least the properties already present in LMD-Z
- Extend LMD-Z to deep atmospheres
- Prefer simplicity & not reinvent the wheel !

## Brief history

- 2009 : started as Indian-French project
- 2010 : work on 2D transport scheme (S. Dubey)
- 2011 : shallow-water model (Ringler et al. , 2010)
- mid-2012 : dry 3D core (Y. Meurdesoif)

# Advancing the hydrostatic equations in time

**Hybrid coordinate $p = A(\eta) + B(\eta)p_s$**

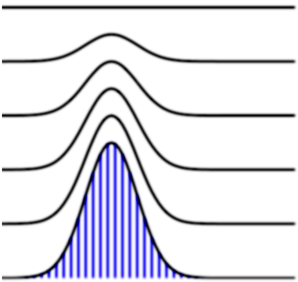
Prognostic : $p_s(\lambda,\phi)$, $(u\,, v\,,\ m\theta,\ mq)(\lambda,\phi,\eta)$

**Mass budget**

$$\frac{\partial m}{\partial t} + \frac{\partial}{\partial \eta}(m\dot{\eta}) + \nabla_\eta \cdot (mu)$$

1. Horizontal mass flux $U = mu \Rightarrow \partial p_s/\partial t$
2. $\Rightarrow$ vertical mass flux $W = m\dot{\eta}$
3. Scalar transport

$$\frac{\partial mq}{\partial t} + \frac{\partial}{\partial \eta}(Wq) + \nabla_\eta \cdot (Uq) = S_q$$



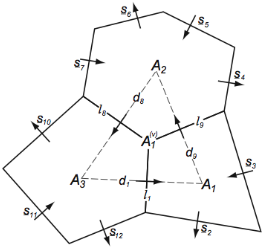
# Advancing the hydrostatic equations in time

## Hydrostatic balance

$$\frac{\partial \Phi}{\partial \eta} + g\frac{m}{\rho(p,\theta)} = 0$$

## Circulation budget

$$\frac{\partial u}{\partial t} + \dot{\eta}\frac{\partial u}{\partial \eta} + (f + \nabla_\eta \times u) \times u$$
$$+\nabla_\eta\left(\frac{u^2}{2} + \Phi\right) + \theta\nabla_\eta \pi \quad = \quad S_u$$



# Old parts and new parts

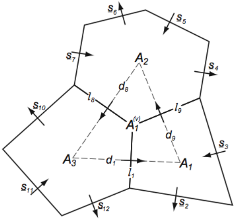
$$\frac{\partial m}{\partial t} + \frac{\partial W}{\partial \eta} + \nabla_\eta \cdot \left(\overline{m}^h u\right) \qquad m = -\frac{1}{g}\frac{\partial p}{\partial \eta}$$

$$\frac{\partial mq}{\partial t} + \frac{\partial}{\partial \eta}\left(W\overline{q}^v\right) + \nabla_\eta \cdot \left(U\overline{q}^h\right) = S_q$$

$$\frac{\partial \Phi}{\partial \eta} + g\frac{m}{\overline{\rho}^v} = 0$$

$$\frac{\partial u}{\partial t} + \frac{\overline{\frac{\partial u}{\partial \eta}}^v \overline{W}^{vh}}{\overline{m}^h} + \overline{(f + \nabla_\eta \times u) \times u}^{TRiSK}$$

$$+\nabla_\eta \left(\overline{\frac{u^2}{2}}^h + \Phi\right) + \overline{\theta}^h \nabla_\eta \pi = S_u$$

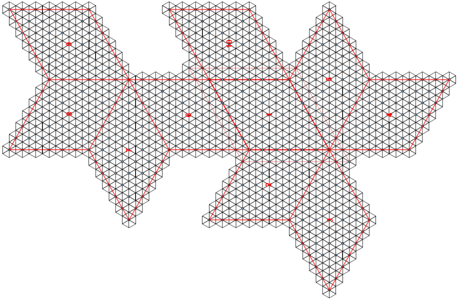


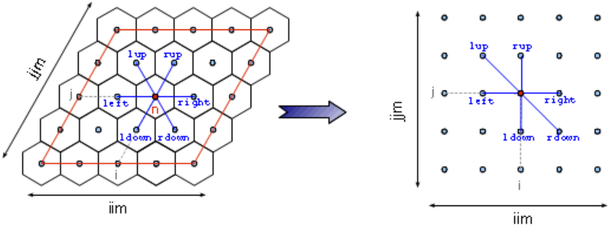

*Thuburn et al., 2009 ;*
*Ringler et al., 2010*

*Miura (2007) ;*
*Dubey et al., submitted*

*see you in Cambridge*

# The icosahedral grid is structured





# Ongoing work

## Planned features

- Parallel I/O (XIOS, Y. Meurdesoif)
- Conservative regridding (E. Kritsikis)
- Deep-atmosphere dynamics (M. Tort)
- Grid stretching

## Potentially desirable features

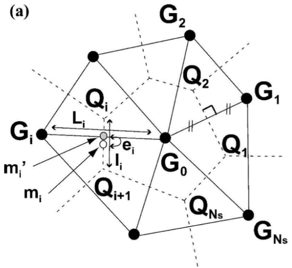
- Non-orthogonal C-grid (J. Thuburn, PDEs on the Sphere)
- Conservative grid nesting (see M. Aechtner)
- Other aproaches : well-balanced finite volumes (F. Bouchut), geometric schemes (F. Gay-Balmaz)

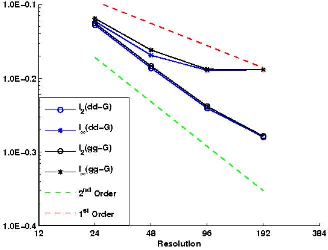
# Gradient reconstruction and scalar DOFs

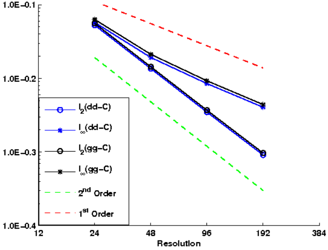
- Problem : first-order estimate of gradient given values around a given cell
- Explicit solution : Green-Gauss theorem
- Requires second-order accuracy estimate of point values

$\Rightarrow$ must use centroids of control volumes

*Miura & Kimoto, 2005*



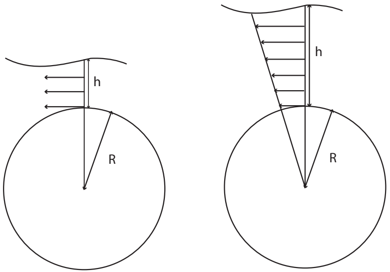
# Deep-atmosphere dynamics

**Deep quasi-hydrostatic equations in a general vertical coordinate**

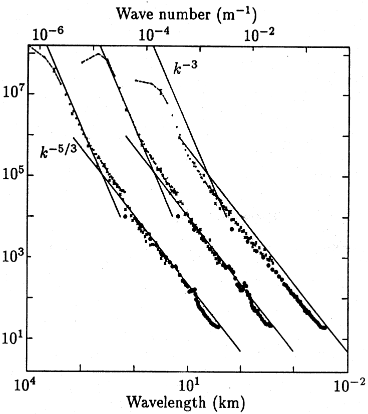
- have time-dependent metric terms
- and a full Coriolis force

**PV-Conserving formulation ?**

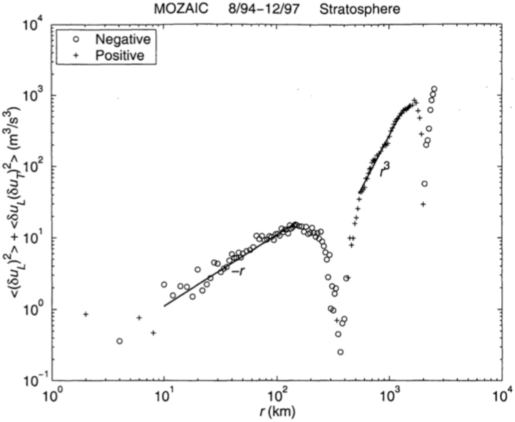
Incorporate metric and entrainment velocity into prognostic variable for velocity
$\Rightarrow$ vector-invariant form



# Deterministic vs statistical benchmarking




*Nastrom & Gage, 1985*




*Cho & Lindborg, 2001*

# Summary

- DYNAMICO is now a (prototype) icosahedral-hexagonal hydrostatic core
- Low-order approach based on
  - discrete conservation,
  - simplicity
  - reuse of suitable existing parts from IPSL or elsewhere
- Proper choice/interpretation of degrees of freedom essential
- Goal is to put it to effective use as soon as possible on Earth and planets

- Deterministic benchmarks good for bug hunting / accuracy issues
- But how much can we really learn from them ?
- "statistical" test cases ?